AD-A049 433 TEXAS A AND M UNIV COLLEGE STATION F/G 13/10
CRUDE OIL LOSSES AND POLLUTION, TANKER INERTING AND CLEANING, H--ETC(U)
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of the proposed system. Follow on research must eventually test and evaluate these assumptions (Chapanis, 1972).

System Feasibility

Enough proof now exists for at least continued research on this system. There appears to be no legitimate reason to continue subjecting personnel, equipment, ships/vehicles, stationary tanks, and cargo to the hazards associated with the techniques discussed in prior sections for tank inerting and cleaning. With today's technology there is no justification for human entry into tanks, other than for tank repair and/or modification. Human error is a function of stress, other things being equal, and in-tank work is stressful.

Even using bag techniques (Carmichael, 1972), the cleaning operation must either use a bag for the cargo and a bag-well for the cargo-pushing fluid or a well for the cargo and a bag for the cargo-pushing fluid. Neither of these bag techniques is particularly appealing since contamination is still present in either the well, the bag, or both, especially due to the constant flexing and the corrosive nature of the action that takes place across the bag membrane. For either of these bag techniques, however, the addition of another fluid-entry port is still a requirement and an additional cargo-pushing fluid is also necessary. With the proposed Freon system, no bag is required, the attendant corrosion is eliminated, the entire tank is purged and cleaned, and removal of the cargo-pushing fluid occurs along with removal of the cargo.

In summary, using this system, all of the steps--from tie-up to untieing--should be fast, efficient, safe, nontoxic, and non-polluting. The systematic procedures make use of modern technology and are compatible with projected tanker designs and an ecologically sensitive citizenry (EPA, 1971; 1972). Previously-lost cleaning materials and cargo are recovered apparently and significantly increasing a tanker's per-voyage cargo capacity. Much of the previously required on-board inerting and cleaning equipment may be removed from the tanker. Equipment space and slop-tankage should be liberated for active cargo or ballast use, once authorities agree to the changes in oily-waste containment requirements. These factors should help to offset the proposed capital expenditure ultimately sustained by the carrier while the improvement in safety and clean-up activities should satisfy the most fiscally-cautious port authorities. It is anticipated that loading and unloading times will also be reduced by the system.

If the next cargo is located at the discharge port, with full-time tank usage, the tanker does not require the usual ballasting between ports nor does it support the practice of off-shore oily-waste dumping. With the proposed system, the tanker does not sustain the usual downtime needed for ventilation or gas-free certification. It can therefore be on-line (in service) much more rapidly giving it more duty-days per year. Once inerted with vaporous Freon and if located with the next compatible cargo so that no cleaning is required, loading can use both sets of lines (input and output

lines) to almost double loading speed while venting the Freon out through the deck hatches. These hatches would be covered with vapor recovery units to reclaim the exiting vaporous Freon.

With the proposed system, like loading, unloading can be significantly faster than before. Any standard hatch can be used for entry of the Bristol or Butterworth type machines through which to inject vaporous Freon to fill the void as detailed in prior sections. In fact, unloading can be hastened further by the maintenance of a slight positive pressure or head with the Freon via shore-side pumps, which was not possible when the tanker was open to and contaminating the atmosphere. Although the hastening mentioned above is insignificant by itself, the slight pressure that is possible with the proposed closed-loop system facilitates monitoring and control functions that would not work with an open system. Specific procedures are suggested in Appendix-B, as a guide.

Using the same basic system concept, various alternatives are possible. These alternatives, can be based upon traffic or fiscal factors, and can be tailored to a given port environment. Where real estate costs are not significant, the extra Freon storage suggested in the prior chapter, "Recommended Field Installation" (p. 64), may be the ideal approach. This approach would allow a smaller, slower and less-costly separation function that could be off-line. Where real estate costs are of prime concern, a larger serial, online separation function would allow the same reaction time with a smaller quantity of Freon.

If the next cargo is not located at the port of discharge, then a given tanker will still be on line much more rapidly than before because of faster discharge of its first cargo, and faster inerting. Inerting with the proposed system begins while the tank is above the UEL and continues through cleaning at below the LEL. The in-rush of inerting material aids evacuation of the cargo since a closed system is used permitting a slight head or pressure to help force the activity through completion. During this entire procedure, no oxygen-rich air or humans will be admitted into the tank. Now, the ship may embark to pick up its next cargo with inerted and cleaned tanks. Vaporous or liquid Freon remaining in the tanks will continue to protect these tanks right up to and including the loading of the next cargo, at the ship's next port of call. Similar to the prior procedure for loading, vapor recovery units capture the remaining Freon while loading the next cargo. Loading speed is almost doubled, no air is introduced, the system remains for all intentions closed, and no new hazards are introduced as the tanks go from below the LEL back up to their full level above the UEL. Ventilation, required only for in-tank inspection, maintenance, or modification, can be achieved as before but, because of Freon's low level of toxicity and excellent flash-point retardation, with less risk to the crews doing such work (Gafafer, 1964).

Thus, operators may achieve reduced costs, as follows. An increased loaded utilization rate with no change in maintenance expenses can be achieved as well as a reduction of ballasted travel

for cleaning between uses. Expense may be further reduced since the Freon inerting/cleaning material is recovered. Where both labor and cleaning materials were expended before, now only in-port cleaning labor is sustained. With the proposed system's attendant hazard reduction, insurance premiums should also be reduced as various proofs of system validity are accumulated. Now, with waterless cleaning, the possibility of waterless ballast runs between cargo-1 discharge and cargo-2 loading if not colocated, are possible and rusting can be reduced. By this means, ship integrity may be improved and human lives may be saved (U. S. Department of the Navy, 1971).

The Need for Follow-Up Research

Much more research must be completed to clearly identify all of the costs, as well as the savings, that will accrue. The system will obviously be expensive due to the equipment and off-shore or port-side real estate alone. Furthermore at current rates of approximately 35¢/pound, Freon-TF is expensive and only available from a few sources. Since no other known system or user employs Freon quantities approaching these requirements, there may be room for price negotiations.

Follow-up research should also attempt to get universal adoption of the system. Ultimately, standardization and implementation of the system will have to be promulgated by a multi-national body such as the Inter-Governmental Maritime Consultative Organization to provide the required safety at all ports. It would not be

reasonable to be safe at Port-A only to re-expose the ship, crew and cargo to undo hazards at Port-B. Also, in light of its costs, certain Freon or Freon-imposed losses that could be discovered later as inherent to the system and its components will have to be faced and quantified.

Follow-up research will have to solve the problem of Freon not being compatible with certain cargos, coatings, or materials such as silicon elastomers, polystyrene plastics, or zinc (DuPont, 1972c).

A saving that will have to be shown and is not yet quantified satisfactorily is the total value of recovered oil associated with bilge, ballast and deep tank cleaning operations. There is a documented annual loss of one-billion gallons (or 4.5 million tons) in the Houston Gulf Coast area alone (F. R. Harris, 1972). Furthermore, the bilge and ballast operations are not limited to chemical, oil, and LPG tankers, but applicable to OBO's and dry-bulk freighters as well. Once quantified, it is anticipated that the resulting saving will aid in offsetting the cost of processing the Freon as well as many other costs.

Continued research should uncover methods to broaden the system's application and extend usefulness to the various commodities listed in the latest issue of Table 30.25-1 of the Code of Federal Regulations (CFR)-46 "SHIPPING" (General Services Administration, 1972). This effort should be objective enough to determine whether optimum results can best be obtained by a change of procedures involved specifically with the commodities listed, by modification

of this system, or a combination of the two.

It is important to evaluate possible efficiencies that the system might provide in solving the empty-return dead-heading runs* and other tanker or non-tanker cargo, process, waste-treatment, or handling problems. It is also conceivable that the system could have merit when applied to other industrial problem areas; e.g., cold rolling steel process (U. S. DOI, 1970). These efficiencies may be achieved from such applications by slight modification of the system or by one of the three changes noted in the preceding paragraph.

Lastly, it might be lucrative to evaluate possible efficiencies that might accrue from an accumulation of components from industries that currently supply quality hardware, software or services and that are based in cooperating countries such as those participating through the Safety Of Life At Sea conventions. Perhaps optimized components via improved maintainability, reliability, and/or logistics may be obtainable at no additional expense. In this way, universal appeal may be served by the sharing of not only costs, but also technology. There may be greater participation if the maximum number of participants in the tanker loop have a stake in the ultimate design and are given a chance at the new industrial economic growth that the system is capable of providing.

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*Rapidly cleaned ships may be able to serve transportation in new ways not yet imagined, once they are made available. If only to exclude the water ballast and attending corrosion problems, progress will have been achieved.

Recovery of Contact-Surface and Ullage Vapor Losses

Using Load On Top (LOT) a certain amount of the Freon vapor will be picked up by fresh incoming cargo. Now, if the bulk of the Freon remains in its vaporous state, it will tend to inert the ullage space above the cargo and retain the subject tank in a safe, reduced air or oxygen starved condition. Any free liquid Freon present will sink to the bottom of the tank. This effect is not without merit since the Freon will then tend to keep the tank bottom clean and corrosion-free by reducing sludge formation. A barrier will minimize Freon/crude contamination.

Freon/crude action in a simulated or real-world tanker environment will have to be evaluated further. It seems reasonable to assume that in some cases a finite amount of Freon vapor will remain above the crude. The question in this case is whether the remaining amount will be sufficient to act as an inerting blanket. It also seems reasonable to assume that in other extreme cases a certain amount of liquid Freon will contaminate the crude even via contact surfaces. The question here is whether this contamination is sufficient to require extensive volumes of cargo distillation to reduce the Freon concentration ahead of the refinery process, as discussed in the next subsection.

It is possible for normal ship motion to elevate internal tank temperature above the Freon atmospheric boiling point (118°F) thus helping any free Freon present to remain vaporous (DuPont, 1970). Tests must be performed to identify the amount and rate of occlusion

that takes place as discussed immediately above. The relationship that may exist between occlusion and saturation should also be experimentally determined. During this recommended phase of testing, it will be interesting to note the degree of cooling (if any) that takes place in the tank (see "Test Tank," pg. 39) resulting from any outgassing of the Freon through pressure relief valves and what effect this cooling has.

Because of the relatively high cost of the Freon vapor, recovery units are recommended and assumed in all prior discussions of cargo loading and unloading. These units will capture the exiting Freon enabling a more complete recycle and assuring atmospheric protection. Infra-red techniques employing LIRA-type equipment (MSA, 1972) should be used to allow later visual observation of the Freon in the various simulated crude-oil/tank environments. These techniques will also allow observation of action along the Freon/air interface.

Possible Catalyst Losses in Refining the Crude

If trace amounts of Freon remain occluded within the crude and if the distillation process is used to separate the Freon/crude mixture, it is imperative for this distillation process to be highly efficient. If not sufficiently effective, or if this distillation is not port-shared by all of the contributing refineries as an initial refinery process, any Freon remaining in the crude after distillation can be adverse to further refinery operations. This is due to the chemical contamination of the platinum catalyst by Freon

at elevated crude-oil refinery temperatures. This contamination may impose some new, burdensome repair costs upon the refineries if not properly addressed.

Detail Design Factors

Detail design factors remain to be worked out prior to initiation of a model installation. Typical of these are the additional testing and tradeoffs that will have to be accomplished to answer such questions as (U. S. Department of the Air Force, 1965):

1. Optimum line length, if not dictated by other physical constraints, to minimize sampling reaction-time to faults or tolerance limits.
2. What elements, if any, should have internal power supplies to minimize case penetrations, while accepting a certain degree of calibration and corrosion difficulty.
3. Where to locate the Freon line heater for maximum safety, to inject vaporous Freon during inerting.
4. Optimum Freon input rate for inerting/cleaning versus static build-up.

The Need for a Forum and System Exposure

The program should be expanded to at least point the prospective system users and legislators toward the need for:

1. An understanding of and familiarity with the true value of this waterless system in relation to its cost.

2. Using continuous monitoring by qualified personnel. Most operators are already using certified-safe equipment, and following approved procedures within a somewhat approved/controlled environment. This step can effectively be accomplished by employing U. S. aerospace techniques such as the nine design steps per paragraph 5.4.1 of MIL-STD-882 (U. S. DoD, 1969). Tank cleaning monitors and operators should be properly trained and certified in a manner similar to AFLC AFM 127-100 per 30ZR4625X as defined by the U. S. Air Force Directorate of Safety (U. S. Dept. of the Air Force, 1973d).

3. Getting a uniform/standard approach to the problem and its solution to save:
   a) Personnel turnover, accidents, and life expectancy
   b) Personnel training costs
   c) Port-side facilities and real estate
   d) Ship and equipment down-time
   e) Cargo while increasing per-voyage yield
   f) Inerting and cleaning material
   g) The natural ecology.

A bi-directional interchange of data should expedite solutions to the various problems listed above and may also act to accelerate acceptance of the proposed system.

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APPENDIX-A

Glossary of Research-Related Terms

Using the EPA "Microthesaurus of Air Pollution Terms" as a guide, a list is provided below to identify key areas of interest based upon the problem and the proposed system (solution).

abatement

abrasion reduction

accident prevention

adaptable

additional safety features added

advance warning

airborne tankers

ambient environment

analysis

anxiety reduced

attributes

architectural work space layout

audible feedback

auto-ignition

automation

auxilliary safety function

ballast

behavior

bilges

Blaco-tron (Baron-Blakeslee)

blanketing cargo

blowers eliminated

$C_2Cl_3F_3$

CF_3Br

cargo loss/handling

cargo transfer

catastrophic damage

centralized operation

certification of facility and personnel

chemical certification

classification

cleaning agent recovery

cleanliness improvement

closed-loop operation

cofferdams

cold process

colorimetry

compatibility

comingling of products

compensation

computer support

connect-disconnect times unchanged

conservation of manpower

contamination (cargo/cleaning agent)

continuous sampling included

control (automatic/manual)

control aiding

cooling

corrosive action

cost reduction/benefit/effectiveness

critical incidents

critical temperature

crude oil

degradation

design simplicity

detectors

dielectric strength of Freon

display quickening

distillation

dropping

dry dock use reduced

duration of exposure

duty-cycle capable of being increased

ecological principles

economic growth

efficiency enhancement

electrical hazards

electrolysis

elevated temperature

empirical results

emulsion action

energy conservation

engine room

engineering

equipment utilization

error

estuaries

evaluation

evidence/support

experiments and tests

explosion protection/
proofing

exposure (environmental/
military)

facilities

facility design

fail safe features

falling

federal, state, and local
regulation and support

fire protection/proofing

fixed tanks (tank farms)

flammability range

flash point suppression

flow rate increased

fluorinated hydrocarbon

formula

Freon

galvanic corrosion
reduced

gas freeing

Gascope

geographic location
adaptability

growth potential
provided

halide meter

halogenated hydrocarbon

Halon

harbor

hardware

hazards identified
and controlled

heightened avaiability

hot process

human factors engineering

human stress reduced

human work load
reduced

IMCO

identification of hazards

industrial growth and
support

inert material

inerting agent recovery

infra-red detection

inherent safety

in-port functions expanded

installation ease

instrumentation

insulation resistance

insurance costs minimized

in-tank entry eliminated

integrated

interlocked for safety

International Maritime Consultative Organization

invasion of O_2-laden air

isolation of products

Kuwait Crude

LEL

LOT

leak detection

leaking

liberated on-board space

life expectancy lengthened

lightning protection

liquid products

liquifaction

litigation reduction

Load On Top

logistics

longevity

lower explosive limit

MIUS

MOD

manual functions reduced

maximum up-time and feedback

minimum down-time

minimum waste

miscibility

mission profile

mixing rate

mobile

modifications

minimized

Modified Load On Top

modular

monitoring improved (automatic/manual)

monobromotrifluoromethane

mucking

multi-point (grid) sampling

new process-plant requirement

new products

OBO

observation

off-tank inert-gas generation

off-the-shelf hardware

oil

oily-waste

operations research

optimum configuration

other agents (inerting or cleaning)

out gas (evolve)

overpressure limit

oxidation minimized

oxygen analyzer

oxygen content

oxygen starvation

parallel operation

Pensky-Martens

periodic maintenance (ship/tank) simplified

personnel selection and retention improved

physical hazards

piping systems

planning

plant life

pollution reduced (air/water)

port usage increased (traffic volume)

positive pressure

pourability

precision

prediction of traffic

pressure

procedurally streamlined

procedures

programmable processing

projected growth and importance

pumps

purging

purity/quality enhancement

push-pull operation

rail head installation

rapid results

re-cycle

remote monitoring

response time

restriction of environment

results (immediate)

risk classification

SOLAS

Safety Of Life At Sea

safety of personnel, facilities, equipment and procedures

satisfied current international regulations and goals

scale and sludge removal

scavenging

sea duty of cleaning crew eliminated

sea-going tank ships

security simplified

seepage sensing

self-contained

separation of products

serial operations (now)

shirtsleeve environment

shoreside

simulation

single-point mooring

slipping

socioeconomic factors

software

solvents

speed of reaction

spray systems maintained

standardized procedures

standby safety facilitation

static electricity

stationary tanks

storage increase

stress reduction

superport

"Supership"

supertanker

supervision of entire process from single location

surface tankers (rail, road)

systematic operation

TCTFE

TLV

tank bottoms

tank cooling side effect

tank voiding, purging, inerting, ventilating and cleaning

temperature

test criteria

threshold limit value

time sharing of facilities and personnel

toxicity

tradeoff

training and upgrading personnel

trichlorotrifluoroethane

triple-point

tripping

UEL

ULCC

Ucon

ullage

Ultral Large Crude Carrier

Universe Class

universal

unlimited tank size

upper explosive limit

VLCC

vapor pressure

vapor recovery

Very Large Crude Carrier

viscosity

visual feedback

vulnerability

waste management

waterless solvents

weathering decrease

weight reduction

Worldscale

Yo-Yo

zero discharge

APPENDIX-B

Preliminary Operating Procedures for Reduction of Tanker Inerting and Cleaning Problems and for Pollution Abatement

The hypothetical procedures discussed herein are formulated to be closed-loop, continuous and safe. Beginning with Step-1, the proposed system monitors purity of the Freon, the cargo, and flow rates. The metering system is simple enough to be observed and operated effectively by current personnel without significantly new training. This system is based upon automated techniques using present day technology and off-the-shelf hardware. For the smaller operator or installation, manual operation is valid, safe, and reasonable. For larger facilities, automated techniques are lifewise valid, safe, and reasonable while still using the same basic elements proposed for the smaller installation. This equipment and installation commonality allows for optimum logistics--spares deployment, minimum down-time, and minimum training for operators and maintenance personnel.

For the entire gamut of facility operations, no new or special tools or precautions are required. In fact, because of the improvement in safety and reduction of direct human contact with the cargo, the proposed system is judged to be more foolproof.

The fourth section of the five procedures discussed below suggests extension of the proposed system for fire-fighting--an added capability for merely the addition of manifolding and tankage with

compatible extinguishing material, also a Freon.

A. Cargo Removal with Simultaneous Tank Inerting

1) Tie-up ship at port-side cleaning facility.

2) Connect ground-potential static-electricity-defeating lines.

3) Hook-up input/output lines and vapor recovery units or bladder as determined from the notes below.

4) Run Built-In-Test (BIT) routine prior to the liquid Freon introduction to verify integrity of closed-loop system and pressurability.*

5) Apply power to pumping system to empty tanks, as follows:

a) Pump vaporous Freon into shipboard cargo hold/tanks

b) Pump liquid cargo ashore, etc.

NOTE

Continue Step 5), filling the tank with Freon vapor until all of the cargo is unloaded such that the tank becomes inerted as the cargo is removed. At no point in this procedure has the cargo been exposed to oxygen from the ambient environment.

If cleaning is the next step, in preparation of a new higher-grade cargo, tank inspection, or maintenance procedures, go directly to Procedure B. If not, and ship is to dead head to next port of call, procedure may be terminated at this time. Bladders are to be used instead of vapor recovery units to prevent loss of the inerting material while providing the required amounts of tank breathing (expansion/contraction) due to the environment. Go to Procedure C.

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*This may be accomplished by purely electrical means or by using a slug of vaporous Freon which is a fast, effective and less costly leak-test than application of the liquid Freon.

B. Tank Cleaning*

This procedure assumes completion of the inerting operation discussed above, if required. Also, this procedure assumes that as much cargo has been removed as is possible with the particular tank ship and support facility.

1) With vapor recovery units in place (as opposed to bladders where only inerting is required), switch from vaporous Freon injection to liquid Freon injection.

2) Pump Freon/cargo mixture from shipboard tanks to separation facility, as follows:

   a) Maintain proper pressure equilization by Freon liquid input and by

   b) Recovering escaping vapors through the vapor recovery units

   c) Pass Freon/cargo mixture through scale/solid filtration, skimming or settling tank if sufficient Freon storage is held. Otherwise, go directly to Step-d).

   d) Separate Freon/cargo mixture via distillation station, as follows:

      (1) Vaporize and remove the Freon.

      (2) Re-liquify the Freon for immediate re-use in the cleaning loop.

---

*This operation may also be applied to the safe cleaning of the various bilges, solid-waste-storage tanks, and other closed spaces aboard all commercial vessels (not just tankers). The stipulation of "commercial" vessels is made to classify vessels large enough to make application of this system economically feasible/valid.

(3) Vaporize, remove, re-liquify and store cargo in temporary holding tanks or pump cargo directly into next (long term) storage medium.

(4) Collect and dispose of waste products.

e) Pump Freon into cargo hold/tanks as part of recycle.

f) Repeat cycle (a-e, incl.) continuously until in-line metering system indicates that the ship is empty (devoid of contamination within specified/acceptable limits). This step completes cargo transfer cycle to satisfy the waybill.

3) Run specified number* of pure-Freon rinses through tanks to achieve proper level of purity (depending upon characteristics of past cargo, next anticipated cargo, their possible cross-product combined effects or the purity required for eventual human entry). This step satisfies the carrier.

NOTE

If next cargo is in this facility, it may be loaded using the same pumping station and lines without involving the Freon. Thus at this point the next cargo and its origin should be considered prior to the disconnection routine which follows. Further, ballasting must be considered in light of the next system.**

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*Beyond mere cargo removal, to a level of predetermined cargo-hold purity. This depends upon the next cargo and its peculiarities.

**To totally eliminate contamination of tanks by sea-water it may be feasible to use the liquid Freon as the tanker's ballast between ports if the next port is equipped to cycle/purge and use the Freon in the tanks.

C. Total System Shut-Down (Next Cargo is not Available in this Port At this Time).

1) Close appropriate gate valves to prevent back flow.

2) Reverse the pumps to clear the system and drain the lines of Freon.*

3) Add ballast as required.

4) Remove power from pumping system.

5) Disconnect input/output lines and bladders or vapor recovery units.

6) Disconnect ground-potential static-electricity-defeating lines.

7) Ship may untie and embark to next port of call.

D. Reload (Next Cargo is Located at this Port and is Ready for Loading).

1) Close appropriate gate valves to prevent back flow or contamination of next cargo.

2) Clear system to drain tanks and input/output lines prior to their disconnection or re-use (as in Step-2 of Procedure-C).

3) Close remaining valves etc., as required.

4) Block power to system to assure safety during line manipulations.

5) Disconnect, remove and store output lines that were attached to the ship for removal of its prior cargo unless able to use in 6), below.

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*This draining operation siphons any residual material back behind valving such that there is no pollution/contamination of the port or loss of Freon.

6) Switch input lines and valving such that the next cargo will be loaded into the ship's tanks (not Freon). Use output lines too, if possible.
7) Fill tanks with new (next) cargo.
8) Commence with Step-1 of Procedure-C, above and complete all six steps prior to getting underway.

E. Port-Side Fire-Protection (An Added Capability for a Meager Additional Expense.)

This in-port fire-protection procedure uses the facilities required for the procedures of cargo-transfer through ship-cleaning (A through D, above) with the only additions including:

1) Additional set of valving to connect to standby Freon-extinguishment material.
2) Tankage for compatible extinguishment material (Freon-1301, Halon).

This procedure uses existing pumping techniques (used for cargo transfer and tank cleaning), as follows:

1) Close appropriate gate valves to prevent back flow or contamination of cargo, cleaning-Freon, or extinguishment-Freon.
2) Clear system to drain lines.
3) Switch input and output lines and valving such that the extinguishment-Freon will be pumped from its holding tankage, using both systems in parallel.

3a) While Step-3 is underway, attach appropriate nozzles to lines

if more direct control is needed. This step is to occur in parallel with Step-3.

4) Pump extinguishment material as required.

5) When emergency is relieved, re-establish a readiness posture in accordance with procedures A, B, and/or C.

F. Human Entry for Inspection or Modification

This procedure assumes completion of the cleaning operation discussed in Procedure B.

1) Complete Steps-1, 2, 4 and 5 of Procedure C.

2) Install Coppus-type blowers as per universal practice and ventilate tanks as required.

3) Certify gas-free situation.

4) Continue monitoring for Halides and explosive gases. Also continue monitoring available O_2.

VITA

The author, Mr. Malcolm Mark Brauer, was born June 26, 1932 in New York to Mr. and Mrs. L. H. Brauer. His permanent mailing address is 3612 Southview Circle, Bryan, Texas 77801. He became interested in man-machine systems as a range instrumentation electronic technician with the USAF at AFMTC, Florida.

While a Senior Engineer with the Northrop Corporation for 10 years, the author received his Bachelor of Science degree in 1968 in Architecture at the University of Southern California, where he was a member of the honors program. He also accumulated 13 units towards the Masters degree in Aerospace Safety and Management at USC and was awarded the CMIP medal by Northrop.

He completed his Master of Science degree in Industrial Administration at the University of Dallas in 1972 while Division Human Factors Engineer with Texas Instruments. He took a non-funded scholastic leave of absence from TI to work on the subject system, after the V. A. Fogg disaster.

During his graduate work here at Texas A&M, Mr. Brauer was first a Research Assistant and then a Research Associate. He was given responsibility for the Human Factors Laboratory and the Human Factors Environmental Laboratory. He served as Graduate Student Council Representative for the School of Engineering and was selected for membership in Alpha Pi Mu and Tau Beta Pi, national honorary scholastic engineering fraternities.

This dissertation was typed by Mrs. Sally Brauer.